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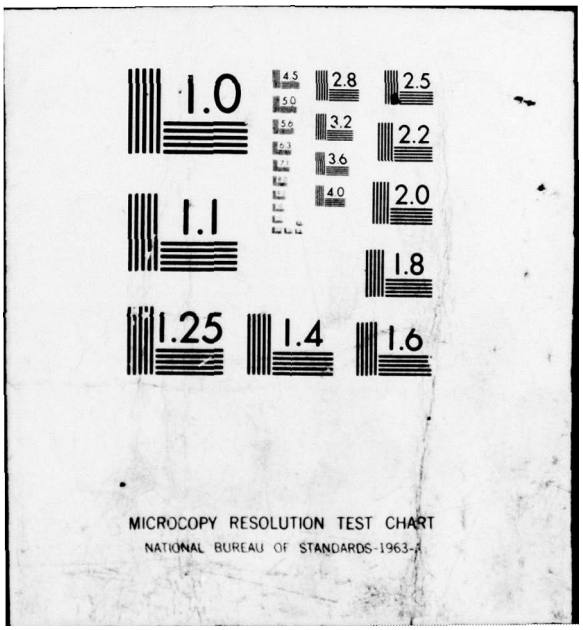
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A heating scheme for nuclear fusion is proposed based on the availability of a high flux, low energy neutron source. The heat is derived in the reaction $Li^6(n,T)He^4$ resulting from the incidence of a low energy neutron beam on a sample of Li^6D. The energy release per reaction, Q = 4.6 MeV, is converted through a electron Coulomb collisions thereby quickly dissociating the solid sample to the plasma state. For $\approx 10^{-3}$ eV neutrons it is estimated that this dissociation occurs in $\approx$ 7 msec for an incident flux of $\approx 10^{17}$ cm^{-2} sec^{-1}. The possibility of further driving the heated fuel to fusion is also discussed.

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PRELIMINARY STUDY OF HIGH NEUTRON FLUX FUSION HEATING

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Abstract

A heating scheme for nuclear fusion is proposed based on the availability of a high flux, low energy neutron source. The heat is derived in the reaction $Li^6(n,T)He^4$ resulting from the incidence of a low energy neutron beam on a sample of Li^6D. The energy release per reaction, Q = 4.6 MeV, is converted through electron Coulomb collisions thereby quickly dissociating the solid sample to the plasma state. For $\simeq 10^{-3}$ eV neutrons it is estimated that this dissociation occurs in $\simeq$ 7 msec for an incident flux of $\simeq 10^{17}$ cm^{-2} sec^{-1}. The possibility of further driving the heated fuel to fusion is also discussed.

1. Introduction

Recent world wide efforts have been initiated to obtain neutron fluxes of the order of 10^{17} neutrons/cm^2-sec, employing high energy pulsed proton bombardment of heavy atoms. Present day thermal neutron fluxes of about 10^{15} neutrons/cm^2-sec are generated by nuclear reactors at Brookhaven, Grenoble and Oak Ridge [1,2].

In this paper we propose a scheme for fusion heating which is based on the availability of high neutron fluxes of low energy. In the envisaged scheme a beam of low energy neutrons is incident on a sample of Li^6D. The low energy neutrons are readily captured by the Li^6 nuclei and release an α particle and a triton through the reaction

$$(1) \qquad Li^6(n,T)He^4$$

The Q value of this reaction is 4.6 MeV. The T particle emerges with 2.63 MeV and the α particle with 1.97 MeV. This energy goes into heating the sample and ionization. In bringing the sample to fusion temperature, it is necessary first to exhaust the crystal energy, thereby effecting a fusion plasma comprised of ionized Li, D, He and T elements.

2. Collision Loss

The emitted particles in reaction (1) lose energy primarily to electron collisions and ionization [3]. The collision loss per unit length is given by the Bethe-Bloch formula [4]

(2) $$\frac{dE_C}{dx} = \frac{2\pi\, n_e\, e^4}{\varepsilon E}\, z^2 \ln gE$$

$$g \equiv 4\varepsilon/ZI,\ \varepsilon \equiv m/M$$

$$I \simeq 11.5 \text{ eV}$$

where z is the charge number of the incident particle. The ionization loss is given by

(3) $$\frac{dE_I}{dx} = \frac{1}{2}\,\frac{1}{\ln gE}\,\frac{dE_C}{dx}$$

With electron density $n_e = 2.37 \times 10^{23}$ cm^{-3} and atomic number $Z \simeq 3$, we obtain for the triton loss,

$$\frac{dE_C}{dx} = \frac{170}{E} \ln 21\, E \text{ (MeV/cm)}$$

(4)

$$\frac{dE_I}{dx} = \frac{85}{E} \text{ (MeV/cm)}$$

Let us assume a mean triton energy of 1.32 MeV relevant to its slowing down trajectory. Then (4) gives, for the triton

$$\frac{dE_C}{dx} = 428 \text{ MeV/cm}$$

(5)

$$\frac{dE_I}{dx} = 0.15\,\frac{dE_C}{dx}$$

With an assumed mean energy of 0.985 MeV for the α particle we obtain

$$\frac{dE_C}{dx} = \frac{907}{E} \ln 16\, E = 2540 \text{ MeV/cm}$$

(6)

$$\frac{dE_I}{dx} = 0.18 \frac{dE_C}{dx}$$

Radiation loss may be neglected compared to collisional loss [5] providing $E/Mc^2 << 1$. This inequality is obeyed for the case at hand. This observation together with (5) and (6) indicate that we may assume the primary loss mechanism to be heating of the lattice through ion-electron collisions.

3. Lattice Deformation Time

The lattice energy of LiD is [6]

(7)
$$E_\ell = 218.8 \text{ Kcal/mole}$$
$$= 5.71 \times 10^{18} \text{ MeV/mole}$$

The completion of this energy leaves the fuel sample in a state of isolated Li^+ and D^- ions. With this energy consumed collisional decrement is still the primary means of energy loss, which now may be assumed to go into heating the sample.

If the original sample thickness is much less than the neutron mean free path in reaction (1), we may assume that the incident neutron flux is roughly maintained through the sample. In this case the neutron reaction rate is

(8)
$$R = JA\ell n\sigma = Jn\sigma V(\text{sec}^{-1})$$

where n is Li number density and V is the volume of the LiD crystal which has cross secional area A and thickness ℓ. The cross section for reaction (1) is σ. The energy released per interaction is

4.6 MeV, which with (8) gives the yield

$$y = 4.6\ J n\sigma\ \text{MeV/cm}^3\text{-sec}$$

The molar volume of LiD is 10.1 cm^3/mole [6] and the last equation gives the molar yield

(9) $$Y = 46\ J n\sigma\ \text{MeV/mole-sec}$$

Comparison with (8) indicates that the lattice energy is supplied in the time

(10) $$t_\ell = \frac{E_\ell}{Y} = \frac{1.2 \times 10^{17}}{Jn\sigma}\ \text{(sec)}$$

Under the somewhat severe assumption that a means of confinement can be applied to roughly maintain the fuel size, then $n = 6 \times 10^{22}$ cm^{-3} and the last equation becomes

(11) $$t_\ell = \frac{2 \times 10^{-6}}{J\sigma}\ \text{(sec)}$$

From low energy neutron data [7] relevant to reaction (1) one may construct the expression

(12) $$\sigma = 135 \times E^{-0.45}\ \text{(E in eV, } \sigma \text{ in barns)}$$

For incident neutron energy $\sim 10^{-3}$ eV this latter formula gives $\sigma = 3 \times 10^3$ b which with (11) gives the lattice deformation time

(13) $$t_\ell = \frac{0.67 \times 10^{15}}{J}$$

It follows that for $J \simeq 10^{17}$, $t_\ell \simeq 7$ msec. Once the lattice heats, the relative n-Li kinetic energy increases thereby decreasing σ and increasing t_ℓ.

4. Fusion Time

In the completely ionized state, each LiD molecule contributes

six particles to the plasma. Thus one mole of original fuel sample is converted to 3.6×10^{24} particles in the completely ionized state. The T-d fusion reaction has its peak cross section [8] at 0.1 MeV. At thermal equilibrium this corresponds to the fusion molar energy

$$E_f = 3.6 \times 10^{23} \text{ MeV/mole} \simeq 6.3 \times 10^4 E_\ell$$

With (9), we then obtain the fusion time

$$t_f = \frac{E_f}{Y} \simeq \frac{0.13}{J\sigma} \tag{14}$$

At $E = 10^{-3}$ eV, this gives the time

$$t_f = \frac{4.3 \times 10^{19}}{J} \text{ (sec)} \tag{15}$$

so that $t_f \simeq 1$ sec for $J \simeq 10^{19}$. This magnitude is somewhat beyond the borderline of present day neutron flux values. Once again we note that this time estimate is low due to the increase in the relative n-Li kinetic energy at elevated temperature.

5. Sample Thickness and Conclusion

The neutron mean free path for the reaction (1) is

$$\ell_n = \frac{1}{n\sigma} = \frac{1.7 \times 10^{-23}}{\sigma} \tag{16}$$

At $E = 10^{-3}$ eV (corresponding to velocity of 400 m/sec) the reaction mean free path is

$$\ell_n \simeq 60 \text{ } \mu\text{m}$$

As stated previously this is the approximate width of the original fuel sample, which must be large compared to the thermalization length

(17) $$\ell_{th} = \frac{E}{dE_C/dx}$$

From (5) and (6) we see that the triton has the longer thermalization length. At triton energy of 1.3 MeV we obtain

$$\ell_{th} \simeq 30 \ \mu m$$

which is approximately half the width of the sample. At larger neutron energy, this inequality becomes more favorable, however both t_ℓ (11) and t_f (14) also increase with larger neutron energy rendering the process still more unfeasible.

In summary, our rough estimates have led to the following conclusion. Namely, that a beam of 10^{-3} eV cryogenic neutrons incident on a thin sample of Li^6D of thickness $\simeq 60$ μm will act as a catalyst for nuclear reactions which will in turn heat the sample. At these values, thermonuclear temperatures may be reached in $\simeq 1$ second, provided a neutron pulse with flux in excess of 10^{19} cm^{-2} sec^{-1} and means of confinement are available. In the absence of this confining mechanism, it may still prove feasible to employ the initial heating scheme in conjunction with more pedestrain plasma confinement-compression devices [9,10].

A mesure of the feasibility of this approach is offered by the Lawson criterion [11]. This criterion stipulates that the product $n\tau$ of particle density n and confinement time τ for the D-T reaction must be in excess of 10^{14} $s\text{-}cm^{-3}$ for positive energy gain. Present day fusion devices have not attained this value. In the heating process of the present scheme we ask that the fuel element, at $n \sim 10^{23}$, be maintained for $\sim 10^{-3}$ sec. which gives $n\tau \simeq 10^{20}$. This large magnitude expresses the difficulties inherent to the proposed scheme.

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